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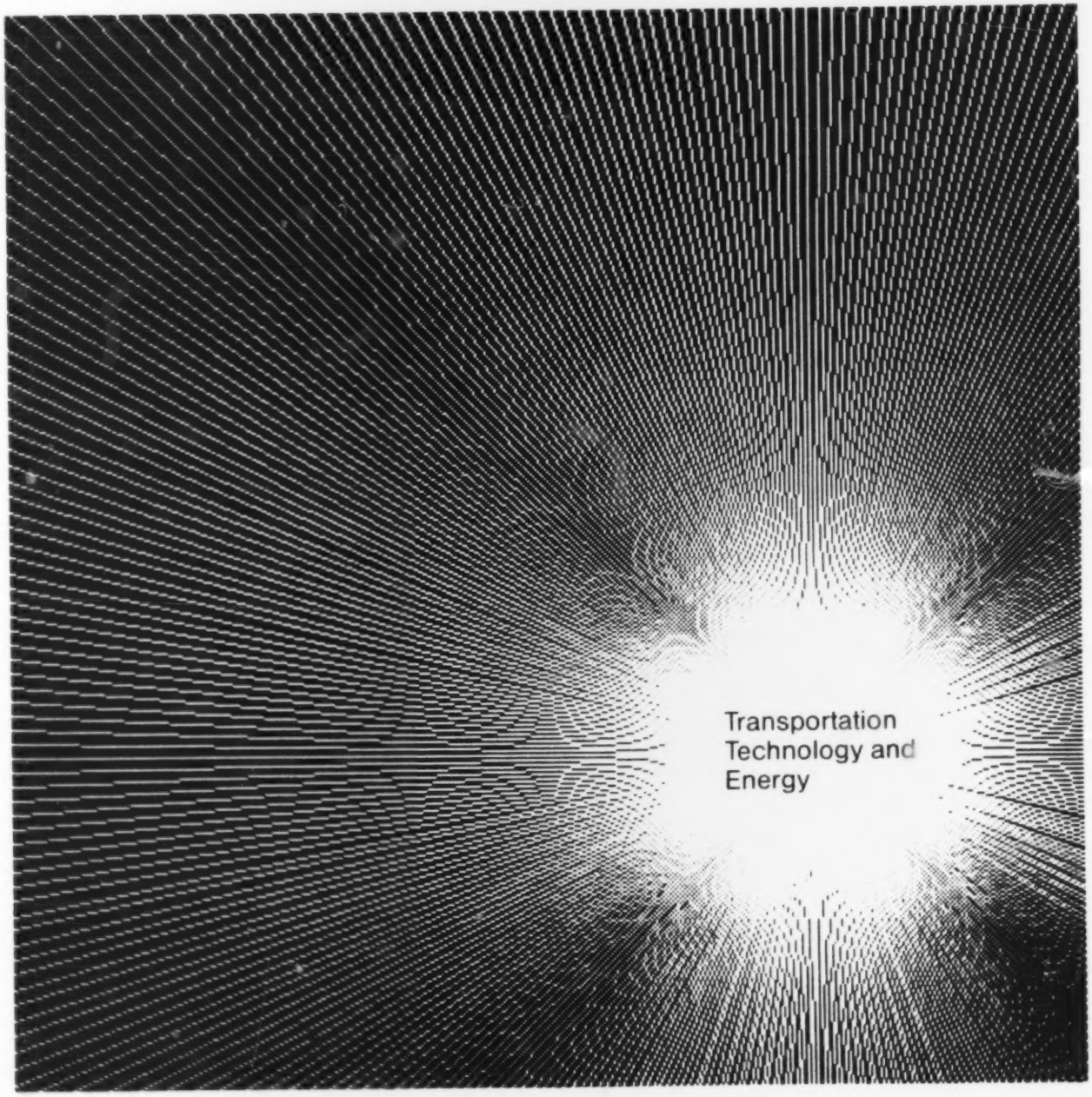
Axle Load Distribution Characteristics of a Triple-Axle Truck Suspension System

CV-85-01



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Abstract:
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Key Words: three-axle group, triple axle, weighing, load sharing

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ABSTRACT

A test of a semitrailer triple-axle suspension, known as the "six-spring" design, revealed that the suspension behaved more like three individual suspended axles rather than a load-equalizing/sharing system. The axle loads were found to vary with axle displacement and chassis attitude, and were often not repeatable. This suspension should, therefore, be considered a three-axle group rather than a triple axle.

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1/ INTRODUCTION

Ever-increasing operating costs have forced the trucking industry to become innovative. These innovations have resulted in the development of some vehicle combinations, axle configurations, and suspension systems designed to equalize axle loads and, as such, are capable of carrying loads close to the maximum permitted by the Ontario Highway Traffic Act.

A triple axle is defined by the Ontario Highway Traffic Act as any three consecutive axles that

1/ have their consecutive centres equally spaced;
2/ have their consecutive centres more than 1 m apart;
3/ are articulated from an attachment to the vehicle, common to the consecutive axles; or
4/ are designed to automatically equalize the load between the three axles under all conditions of loading.

A three-axle group is defined by the Act as three consecutive axles, but not including the front axle of a motor vehicle, that

1/ do not form a triple axle;
2/ are entirely within either a motor vehicle, trailer, or semitrailer;
3/ have spacings between the consecutive axles which do not exceed 2.5 m; and
4/ are not included in a four-axle group.

The triple axle, either alone or with an air-lift axle, is widely used on heavy-haul semitrailers. These trailers are capable of achieving gross combination weights of up to 59 000 kg. This type of trailer configuration is very common in the pulpwood-haul industry and is becoming more popular because the Ontario Highway Traffic Act gives the triple axle an allowable weight advantage over the three-axle group (Table 1[a] and [b]). Presently, any three consecutive axles that have a mechanism or device to distribute the load between axles are considered by the Ministry to be a triple axle. However, it is apparent from experience that many of these mechanical links do not equalize the load properly between the three axles. An investigation was therefore initiated between the Compliance Branch and Research and Development Branch into the various ways in which a triple axle may be weighed. The

Transportation Technology and Energy Branch offered to investigate the mechanics of the suspension system with a view to understanding its behaviour and idiosyncrasies.

This report presents results of a test of a triple-axle suspension of a type known as the "six-spring" design, which is one of the more common types in use.

The objectives of this triple-axle study were to determine the following:

1/ what effect the suspension design has on distributing load to the axles; and

2/ suspension response, and therefore, axle loading, to inconsistencies such as non-level terrain.

Table 1/ Maximum Allowable Weight for Triple-Axle and Three-Axle Group

(a) MAXIMUM ALLOWABLE WEIGHT FOR TRIPLE AXLE

Axle Spacing (Metres)	Maximum Allowable Weight (Kilograms)
2.0 to less than 2.4	19 500
2.4 to less than 2.8	21 300
2.8 to less than 2.9	21 700
2.9 to less than 3.0	22 000
3.0 to less than 3.1	22 400
3.1 to less than 3.2	22 700
3.2 to less than 3.3	23 100
3.3 to less than 3.4	23 400
3.4 to less than 3.5	23 800
3.5 to less than 3.6	24 100
3.6 to less than 3.7	24 400
3.7 to less than 3.8	24 800
3.8 to less than 3.9	25 100
3.9 to less than 4.0	25 500
4.0 to less than 4.1	25 800
4.1 to less than 4.2	26 200
4.2 to less than 4.3	26 500
4.3 to less than 4.4	26 900
4.4 to less than 4.5	27 200
4.5 to less than 4.6	27 600
4.6 to less than 4.7	27 900
4.7 to less than 4.8	28 300
4.8 or more	28 600

(b) MAXIMUM ALLOWABLE WEIGHT FOR THREE-AXLE GROUP

Axle Spacing (Metres)	Maximum Allowable Weight (Kilograms)
2.0 to less than 2.4	19 000
2.4 to less than 2.6	20 400
2.6 to less than 2.8	21 000
2.8 to less than 2.9	21 400
2.9 to less than 3.0	21 700
3.0 to less than 3.1	22 000
3.1 to less than 3.2	22 400
3.2 to less than 3.3	22 700
3.3 to less than 3.4	23 000
3.4 to less than 3.5	23 400
3.5 to less than 3.6	23 700
3.6 to less than 3.7	24 000
3.7 to less than 3.8	24 400
3.8 to less than 3.9	24 700
3.9 to less than 4.0	25 000
4.0 to less than 4.1	25 400
4.1 to less than 4.2	25 700
4.2 to less than 4.3	26 000
4.3 to less than 4.4	26 400
4.4 to less than 4.5	26 700
4.5 to less than 4.6	27 000
4.6 to less than 4.7	27 400
4.7 to less than 4.8	27 700
4.8 to less than 4.9	28 000
4.9 to less than 5.0	28 300
5.0 or more	28 600

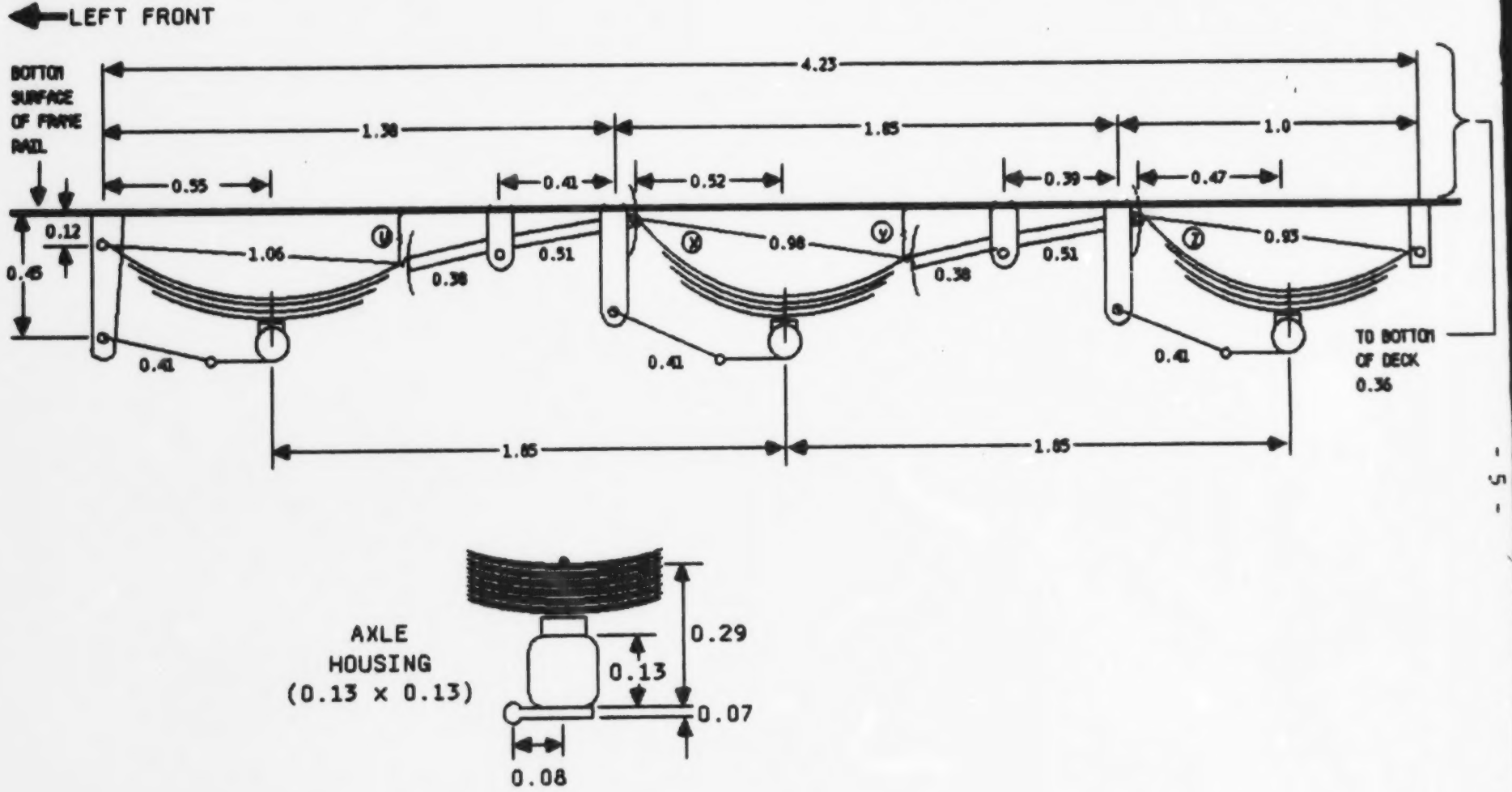
SOURCE: Ontario Highway Traffic Act, 1984.

2/ THE TEST VEHICLE

The trailer examined was taken directly from highway usage and is a four-axle (triple axle and one air-lift axle), standard-design, flatbed semi-trailer. It had been used extensively and was considered to be in typical condition. Its suspension might therefore be typical of those in use on Ontario highways, so test results should provide an indication of real-life suspension behaviour. The triple axle had a variety of tire sizes, tire tread depths, and rim diameters and was found to have unequal axle spacings. All testing was performed with the air-lift axle up while being towed by a Ministry tractor. The suspension system is shown in Figures 1 and 2, and the test trailer specifications are shown in Table 2.

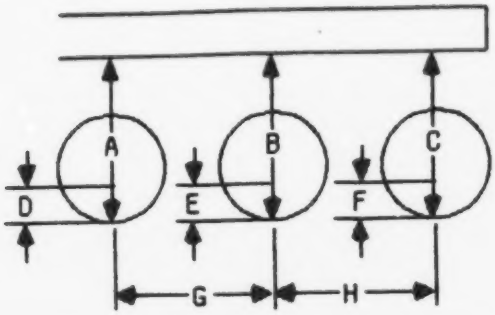
Table 2/ Test Trailer Specifications

SERIAL MODEL:	Manitoulin Transport Trailer #6714 Lic. 399894 Flatbed Type Semitrailer
SUSPENSION:	Triple Axle 8 Leaf Springs per Axle per Side 1.83 m (72 in) Axle Spacing (see Figure 2 for Basic Suspension and Tire Measurements)
TIRES:	Bridgestone V Steel Radial 11R22.5 and 10.00 R20 Michelin XZA Radial 11E 22.5 (See Figure 3 for Tire Layout)
PAYLOAD:	36 364 kg
TRIPLE AXLE: (unloaded)	5980 kg (Oakville Scale)
TRIPLE AXLE: (loaded)	28 384 kg (Putnam Scale)



NOTE: ALL MEASUREMENTS IN METRES

Figure 1/ Test Vehicle Suspension System

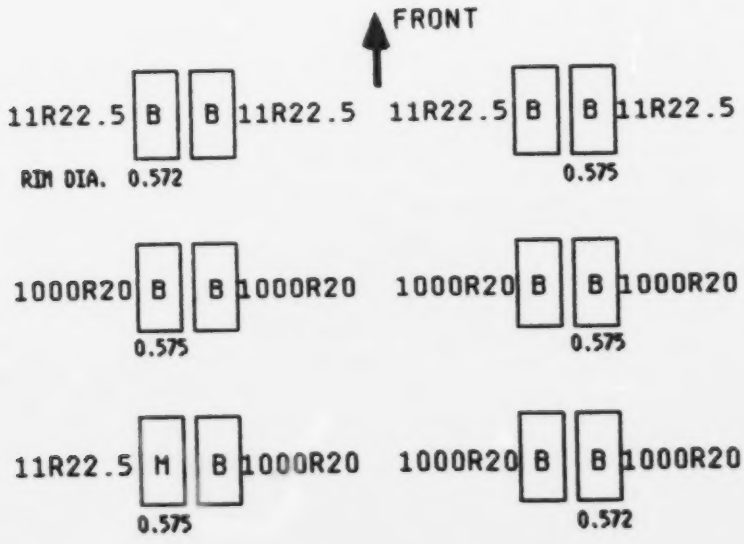


NOTE: ALL MEASUREMENTS IN METRES

D,E, & F ARE
RIM-TO-GROUND MEASUREMENTS

	A	B	C	D	E	F	G	H
UNLOADED								
LEFT SIDE	1.303	1.285	1.257	0.232	0.229	0.216	1.854	1.828
RIGHT SIDE	1.289	1.263	1.229	0.219	0.225	0.208	1.879	1.803
LOADED								
LEFT	1.232	1.219	1.206	0.206	0.203	0.189		
RIGHT	1.235	1.213	1.197	0.197	0.200	0.197		

Figure 2/ Basic Suspension and Tire Measurements



B - BRIDGESTONE VSTEEL RADIAL H
M - MICHELIN XZA

NOTE: ALL MEASUREMENTS IN METRES

Figure 3/ Tire Layout

3/ TEST EQUIPMENT AND PROCEDURES

3.1/ Test Sites

Field weighing tests were conducted at the Oakville North Weigh Station (QEW) and the Putnam South Weigh Station (401).

The Oakville site was used to obtain unloaded axle weights and suspension dimensions. The scale has the capacity to weigh two axles simultaneously.

The Putnam site is located 20 km east of London on Highway 401. This facility has two scales in line. One scale has a two-axle capacity, and the other a three-axle capacity. All loaded axle testing and suspension characteristic testing was conducted at Putnam. The Putnam weigh station is shown in Figures 4 and 5.

3.2/ Test Procedures

By subjecting the trailer axle to a series of deflections over both scales, the individual axle loads can be isolated and examined.

The purpose of the different axle deflections is to induce suspension travel and detect distribution of load between the three axles.

The displacements selected were 3.5 and 8.71 cm at each individual axle. Each axle was raised separately (by blocks), leaving the other two on the ground. All four tires on the raised axle were elevated the same distance when the axle load measurements were taken. The loads per axle and relative tire suspension motion and displacements were recorded. Test conditions and scales are shown in Figures 6 and 7.

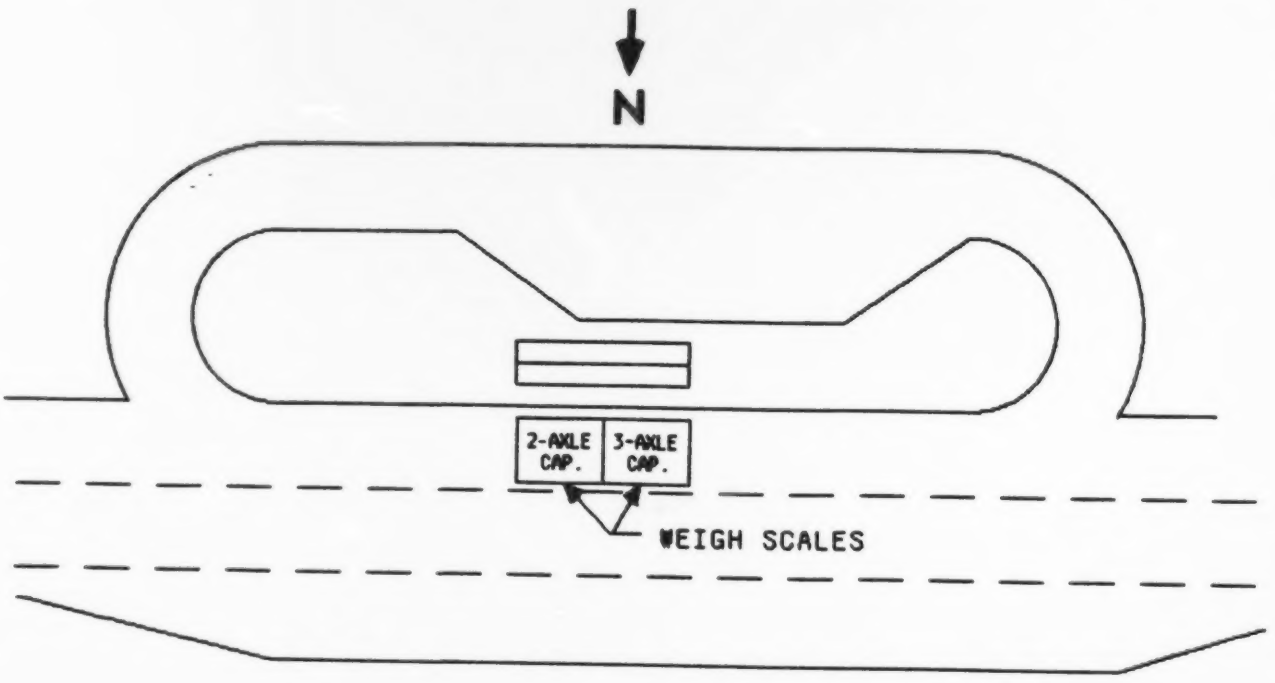


Figure 4/ Layout of Putnam Weigh Scale

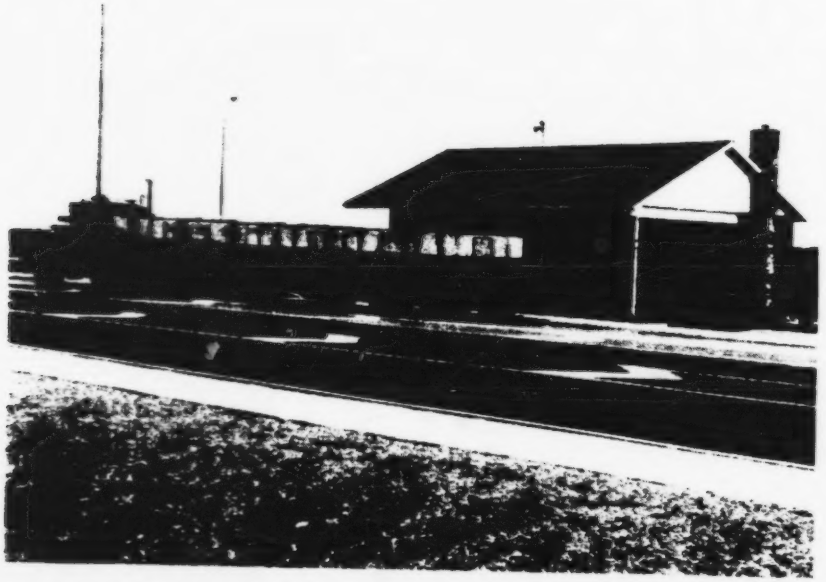


Figure 5/ Test Vehicle at Putnam

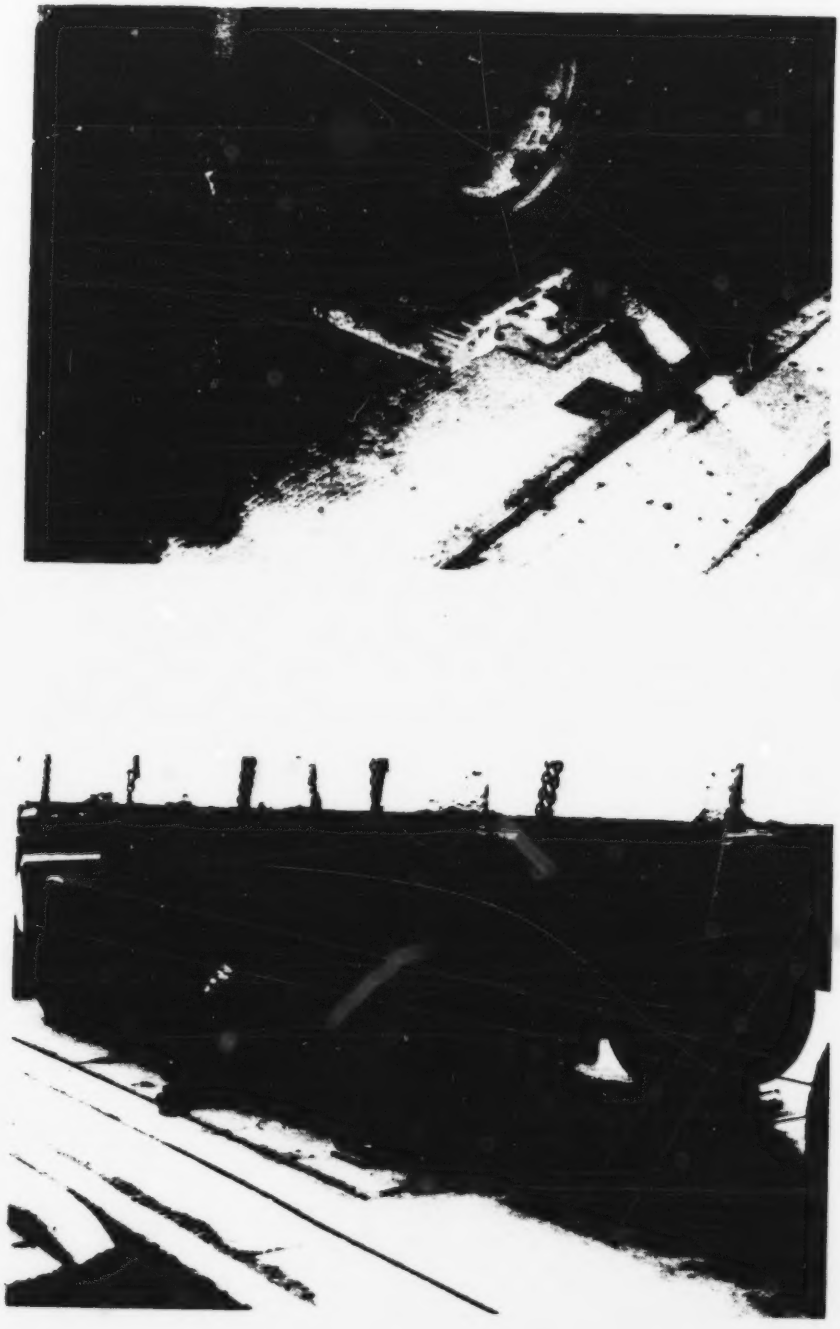


Figure 6/ Using Portable Scales to Lift Axle, and the Recording of Suspension Travel

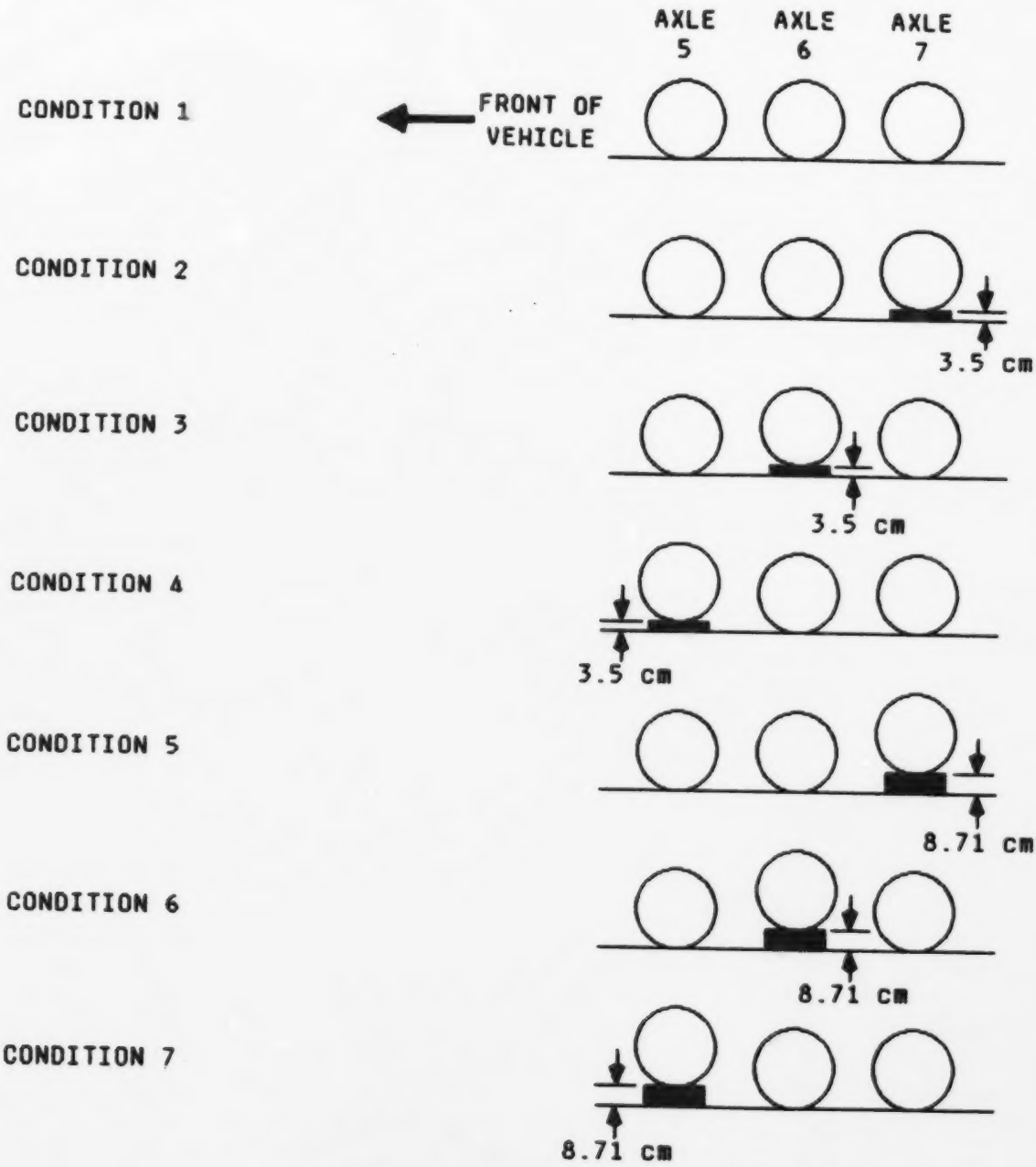


Figure 7/ Test Conditions

4/ RESULTS

The individual ground load reactions, as measured, are shown in Figure 8. Figure 9 shows the axle pickup reactions, which are the overall ground reactions less an estimated 682 kg unsprung weight for each axle. This figure also shows the total reactive moment to support the trailer from the axle U-bolts. The different suspension mechanism attitudes, chassis, and tire displacements are shown in Figure 10(a) and (b).

Figure 11 shows the attitude response of the trailer at the various loading configurations. The increase or decrease in axle load, both absolute and percentage, as a result of relative displacement is shown in Table 3. The chassis suspension U-bolt and spring reactions/deflections are shown in Table 4. The relative axle displacement experienced, less tire deformation, is shown in Table 5.

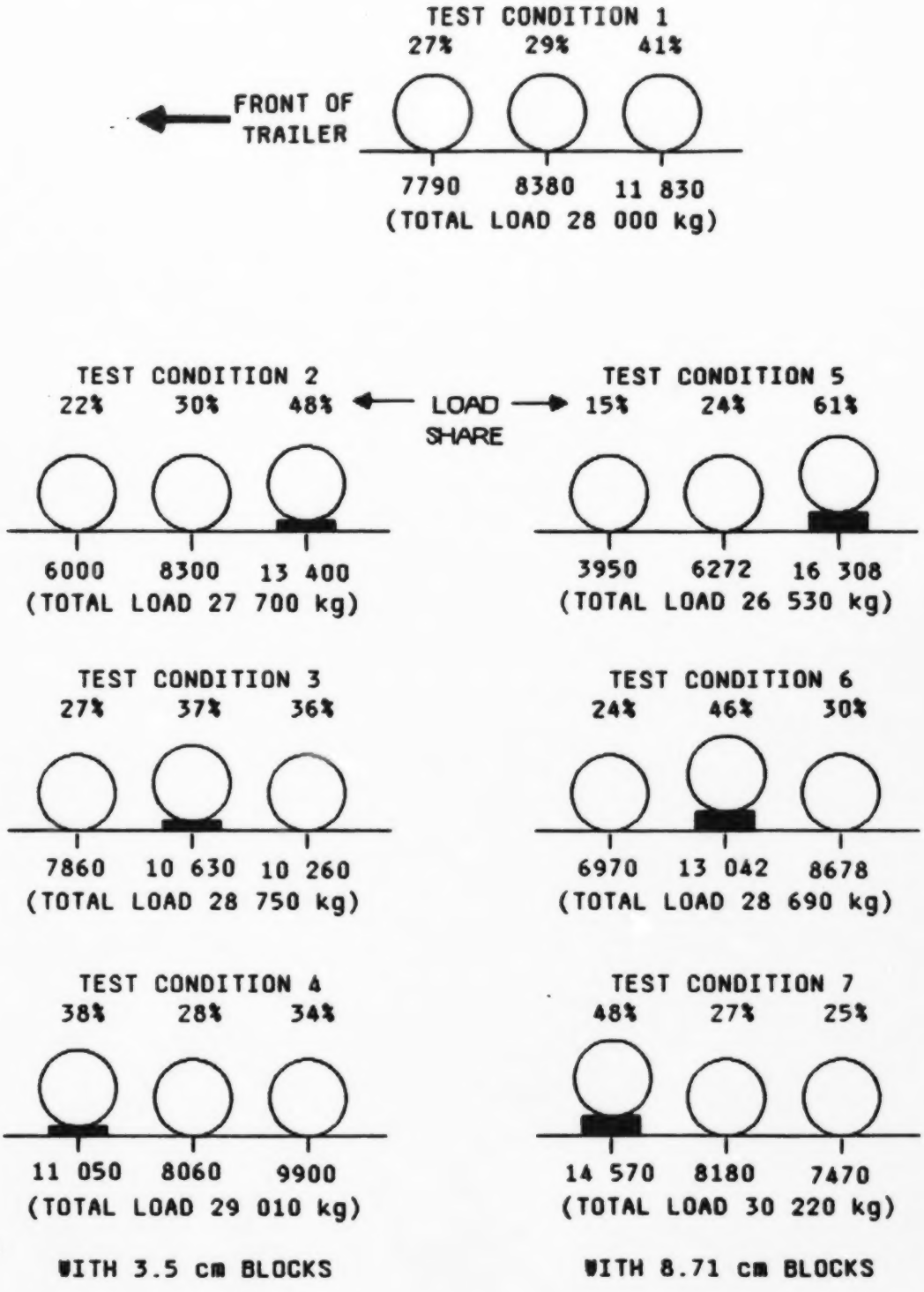


Figure 8/ Tire Set Load Reactions for Various Blocks and Block Locations

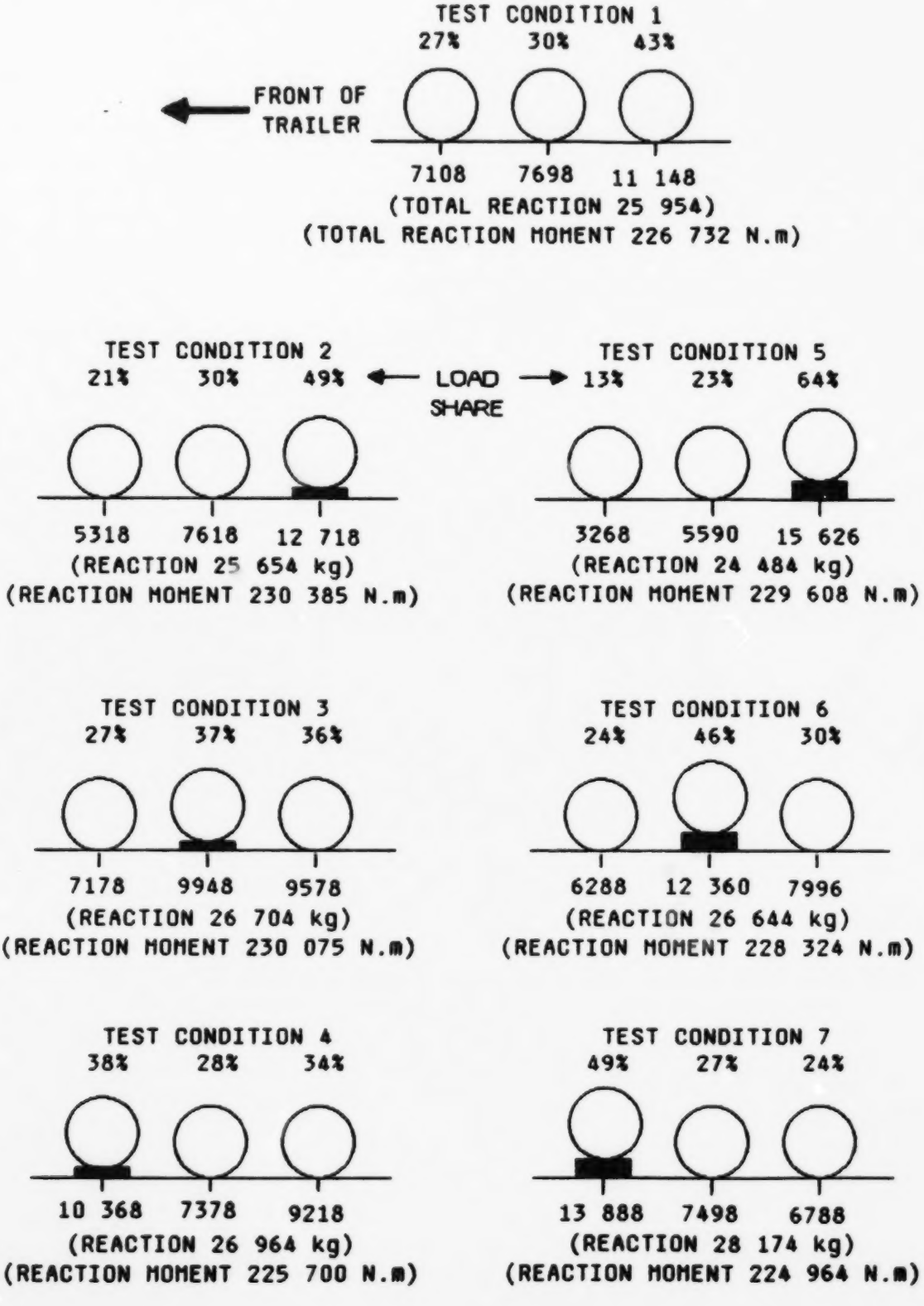
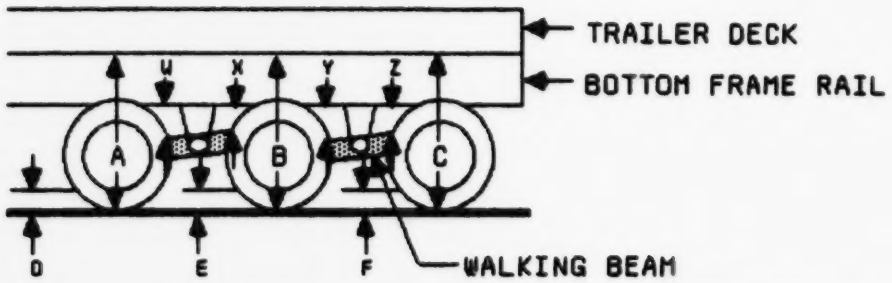


Figure 9/ Sprung Load Reactions at Axle U-Bolts for All Test Conditions

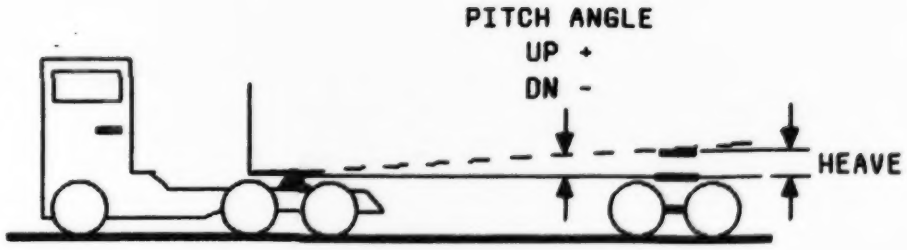


TEST COND.	W		X		Y		Z		A		B		C		D		E		F	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
1	20.32		12.07		19.38		15.57		123.19	123.52	121.92	121.29	120.65	119.71	20.65	19.69	20.32	20.02	18.90	19.69
2	20.96	18.75	11.43	13.97	20.96	19.38	13.97	14.61	124.16	124.16	122.89	122.25	122.25	121.62	20.32	20.32	20.65	20.32	18.11	18.75
3	22.56	20.32	9.86	12.07	17.48	16.03	17.15	17.78	124.16	124.46	122.25	121.92	121.62	119.71	20.02	19.38	19.38	19.38	19.05	20.02
4	18.75	16.51	13.67	16.21	19.38	17.78	15.57	16.21	123.83	124.79	122.56	121.92	121.29	120.02	19.38	18.42	20.02	20.02	19.20	19.69
5	20.96	18.42	11.76	14.30	23.19	21.59	12.40	12.70	125.43	125.43	125.43	125.10	125.10	119.71	21.29	20.47	20.96	20.47	16.84	18.11
6	22.86	21.29	9.47	10.80	14.94	13.67	19.05	20.02	125.43	125.43	124.79	124.46	123.52	122.56	20.80	19.38	18.57	18.42	19.20	20.02
7	16.21	14.30	15.88	19.05	19.05	17.48	15.88	16.84	125.10	126.06	123.83	123.52	122.25	121.92	17.78	17.53	20.02	19.69	19.69	20.02

Figure 10(a)/ Attitudes and Displacements of Tri-Axle Suspension (cm)

TEST COND.	W	X	Y	Z	A	B	C	D	E	F
1	20.32	12.07	19.38	15.57	123.34	121.62	120.17	20.17	20.17	19.28
2	19.84	12.70	20.17	14.30	124.16	122.56	121.92	20.32	20.47	18.42
3	21.44	10.95	16.74	17.48	124.31	122.07	120.65	19.69	19.38	19.53
4	17.63	14.94	18.57	15.88	124.31	122.25	120.65	18.90	20.02	19.46
5	19.69	13.03	22.38	12.55	125.43	125.25	124.94	20.88	20.73	17.48
6	22.07	10.16	14.30	19.53	125.43	124.61	123.04	20.09	18.49	19.61
7	15.24	17.48	18.26	16.36	125.58	123.67	122.07	17.70	19.84	19.84

Figure 10(b)/ Attitudes and Displacements Averaged Left and Right (cm)



CONDITION	AXLE DISPLACEMENTS RELATIVE TO CHASSIS BASED ON CONDITION #1 (cm)			TRAILER ATTITUDE (cm), (DEGREES)	
	AXLE 5	6	7	HEAVE + up - dn	PITCH + up - dn
1	0	0	0	0	0
2	- 0.635	- 0.635	+ 2.616	+ 0.965	+ 0.25°
3	- 1.422	+ 1.270	- 0.229	+ 0.330	0°
4	+ 2.235	- 0.787	- 0.330	+ 0.635	- 0.05°
5	- 1.346	- 3.099	+ 6.579	+ 3.658	+ 0.35°
6	- 2.137	+ 4.674	- 2.540	+ 3.023	- 0.05°
7	+ 4.674	- 2.388	- 1.346	+ 2.057	- 0.05°

Figure 11/ Heave and Pitch Attitudes During Loading

Table 3/ Axle Load Sharing

(a)

TEST CONDITION	Percentage Increase Load over No-Displacement (Sprung Load) Condition		
	AXLE 5	AXLE 6	AXLE 7
1	0	0	0
2	+25.2%	-1.04%	+14%
3	+1.0	+29.2	-14%
4	+46%	-4.2	-17.3
5	-54	-27.4	+40.1
6	-11.5	+60.5	-28.2
7	+95	-2.6	-39.1

(b)

TEST CONDITION	Actual Load Increase over No-Displacement Condition (kg)			
	AXLE 5	AXLE 6	AXLE 7	TOTAL
1	0	0	0	0
2	-1790	-80	+1570	-300
3	+70	+2250	-1570	+750
4	+3260	-320	-1930	+1010
5	-3840	-2108	+4478	-1467
6	-820	+4662	-3152	+690
7	+6780	-200	-4360	2220

Table 4(a)/ Relative Deflection at Axle Pickup as a Result of Walking Beam Motion (cm)

TEST CONDITION	AXLE 5	AXLE 6	AXLE 7
1	0	0	0
2	+0.25	-0.70	+0.64
3	-0.56	+1.86	-0.95
4	+1.35	-1.03	-0.16
5	+0.32	-1.98	+1.51
6	-0.86	+3.49	-1.98
7	+2.54	-2.14	-0.40

+ up
- down

Table 4(b)/ Relative Leaf Spring Deflections (cm)

TEST CONDITION	AXLE 5	AXLE 6	AXLE 7
1	0	0	0
2	-1.52	+0.06	+0.48
3	-1.02	+0.36	+0.16
4	+0.24	+0.08	0
5	-1.91	-0.87	+0.73
6	-1.22	+0.64	-0.40
7	+1.42	-0.08	-0.40

+ compressive
- tensile

Table 5/ Relative Axle Displacements Corrected for Tire Deflections (cm)

TEST CONDITION	AXLE 6	AXLE 7	AXLE 8
1	0	0	0
2	-0.16	-0.32	+0.87
3	+0.48	+0.79	-0.24
4	+1.27	+0.38	-0.16
5	-0.71	-0.56	+1.83
6	+0.08	+1.67	-0.32
7	+2.46	+0.32	-5.56

+ contract

- expand

5/ ANALYSIS

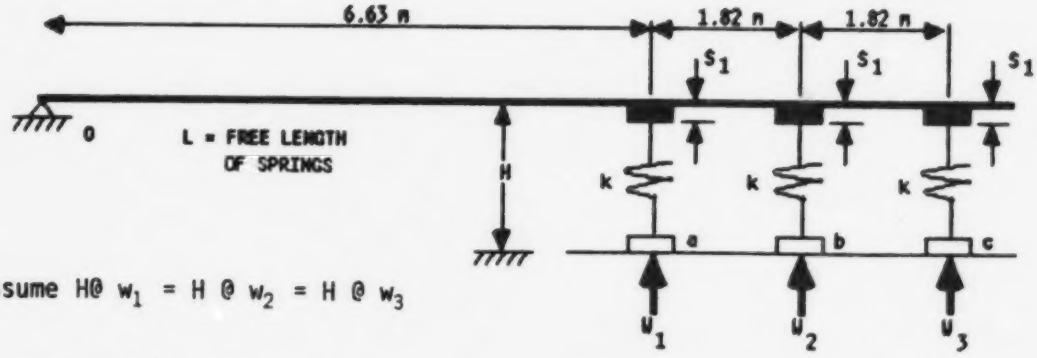
5.1/ General Overview

The three axles on the rear of the test trailer can act either as a tri-axle, i.e., acting through a load equalizing suspension, or as three individual axles independent of each other, or a combination of both.

To better understand the test axle set, mathematical models of both a triple-axle suspension and a three-axle suspension were developed. Blocks similar to those used in the actual tests were placed under the tires of the models, and the resulting loads and displacements were calculated. These data were then compared to the actual test data to see how the actual axle/suspension system compared to the two different models.

Figure 12 shows the actual axle deflection as a function of load applied, thereby giving an approximate spring constant for each axle in the system. For the triple-axle model, this constant was assumed to be K = 788 kg/cm.

5.2/ Three-Axle Model



assume H@ w_1 = H @ w_2 = H @ w_3

$W_1 = k\delta_1 = K(L - H + a + S_1)$

$W_2 = k\delta_3 = K(L - H + b + S_2)$

$W_3 = k\delta_3 = K(L - H + c + S_3)$

W_1 = 7108 kg, W_2 = 7698, W_3 = 11 148 @ a=b=c=o

Total moment about "0" from data = 226 732 N•m

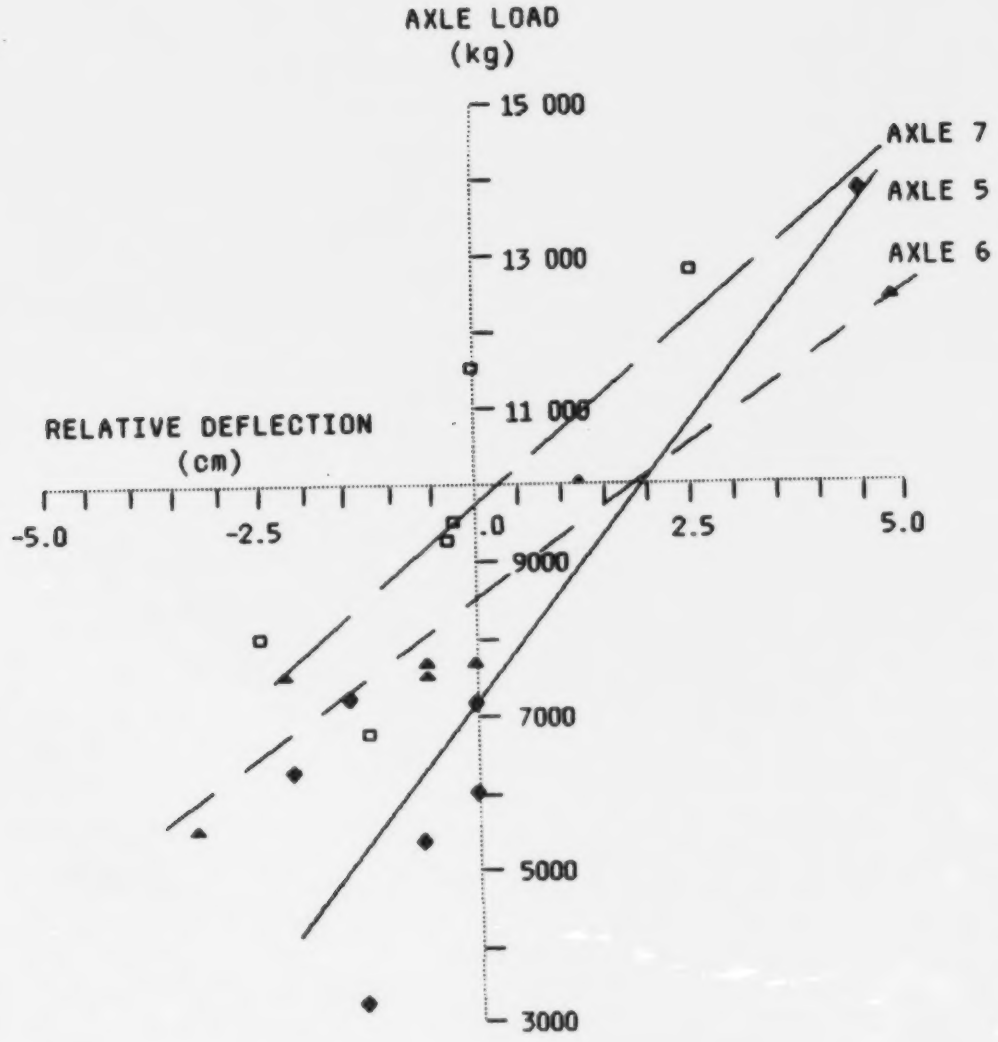


Figure 12/ Overall Axle Load/Relative Deflection Curves

where K = spring constant of axle = 788 kg/cm

L = free length of spring

$S_{1,2,3}$ = initial pre-displacement to achieve condition (1) loads

a,b,c = block heights under axle 5, 6, and 7, respectively

$\delta_1\delta_2\delta_3$ = deflections of axles

W_1,W_2,W_3 = loads at suspension pickups at axles 5, 6, and 7, respectively

$$\Sigma M_0 = 0$$

$$\therefore 6.63W_1 + 8.45W_2 + 10.7W_3 = 226\ 732 \quad (a=b=c=o) \tag{1}$$

To find wedges* S_1, S_2, and S_3 presently existing in axles,

$$W_1 = 7108 = 788(L - H + 0 + S_1)$$
$$9.020 = (L + S_1) - H$$
$$H = L + S_1 - 9.020$$

$$W_2 = 7698 = 788(L - H + 0 + S_2)$$
$$9.769 = (L + S_2) - H$$
$$H = L + S_2 - 9.769$$

$$W_3 = 11\ 148 = 788(L - H + 0 + S_3)$$
$$14.147 = (L + S_3) - H$$
$$H = L + S_3 - 14.147$$

Since H-L = constant, then

$$(S_3 - 14.147) = (S_2 - 9.769) = (S_1 - 9.02)$$
$$\therefore S_1 - S_2 = -0.75 \text{ cm and } S_1 = 0$$
$$S_2 - S_3 = -4.382 \text{ cm} \quad \therefore S_2 = 0.75 \text{ cm}$$
$$S_1 - S_3 = -5.131 \text{ cm} \quad \therefore S_3 = 5.131$$

*Wedge is a suspension term used to denote any spring system preload on axle or wheelset as a result of pretensioners, spring anchor damage, or extraneous influence due to dirt, foreign matter, etc., at a spring mounting point. The term comes from the fact that early automobile racers used wedges to preload their coil springs (measured in cm).

Dividing (1) by 6.63 we get

$W_1 + 1.275W_2 + 1.614W_3 = 34\ 198$

and substituting for W_1, W_2, and W_3

$(L - H + a + 0) + 1.275(L - H + b + 0.75) + 1.614(L - H + c + 5.131) = 34\ 198/788$

$\therefore\ 3.889(L - H) + a + 1.275b + 0.956 + 1.614c + 8.281 = 43.50$

$3.889(L - H) + a + 1.275b + 1.614c = 34.161$

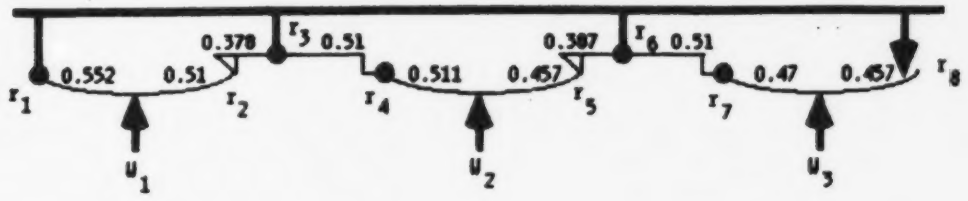
If L = 1.36 m, then

$$H = \frac{a + 1.275b + 1.614c + 494.64}{3.889}$$

From this relationship, the following can be derived:

Test Cond.	a (cm)	b (cm)	c (cm)	H (cm)	w_1 (kg)	w_2 (kg)	w_3 (kg)
1	0	0	0	127.2	6 934	7 525	10 977
2	0	0	3.5	128.50	5 910	6 501	12 711
3	0	3.5	0	128.33	6 044	9 393	10 087
4	3.5	0	0	128.09	8 991	6 824	10 276
5	0	0	8.71	130.80	4 098	4 689	15 004
6	0	8.71	0	130.05	4 689	12 143	8 732
7	8.71	0	0	129.43	12 041	5 768	9 221

5.3/ Equalizing Axle Model



Force Considerations

Equation 1 in three-axle model:

$$6.63W_1 + 8.45W_2 + 10.7W_3 = 226\ 732 \text{ (from actual data)} \qquad (1)$$

From actual suspension geometry:

$\sum$ Moments about r_1: $0.552W_1 = 1.062r_2$ $\quad \therefore r_2 = 0.518W_1$

and $r_1 = 0.482W_1$

Likewise: $r_4 = 0.4675W_2$ $\quad r_7 = 0.493W_3$

$r_5 = 0.5325W_2$ $\quad r_8 = 0.509W_3$

Balancing about r_3 and r_6:

$0.378 \times 0.518W_1 = 0.51 \times 0.4675W_2$ $\quad \therefore 7.705W_1 = 9.35W_2$

$0.5325W_2 \times 0.378 = 0.51 \times 0.493W_3$ $\quad \therefore 7.920W_2 = 9.86W_3$

$$W_1 = 1.2135W_2 \qquad (2)$$

$$W_2 = 1.2449W_3 \qquad (3)$$

Substituting into (1):

$$8.05W_2 + 8.45W_2 + 8.249W_2 = 226\ 732$$

$\therefore 24.75W_2 = 226\ 732$ $\quad \therefore W_2 = 9161$

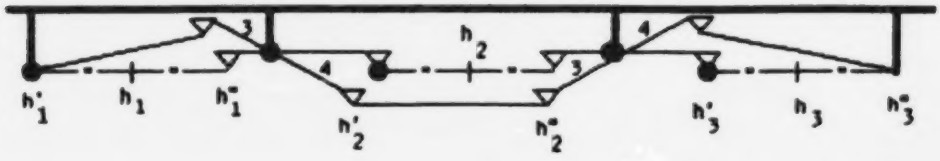
$\therefore W_1 = 11\ 117$ kg

$W_2 = 9\ 161$ kg

$W_3 = 7\ 359$ kg

These values remain relatively constant as long as suspension does not "bottom."

Ride Height Consideration



$2h_1 = h_1"$ (4)

$h_1" = -{}^{3}/_{4}\, h_2'$ (5)

$\frac{h_2' + h_2"}{2} = h_2$ (6)

$h_3' = -{}^{4}/_{3}\, h_2"$ (7)

$h_3' = 2h_3$ (8)

$-{}^{4}/_{3}\, h_1 - {}^{3}/_{4}\, h_3 = h_2$ and $H = 50$

CASE	CONDITIONS(cm)	RIDE HEIGHT(cm)
1	$h_1 = h_2 = h_3$	127
2	$h_1 = h_2$; $h_3 - h_2 = 3.5$	127.8513
3	$h_1 = h_3$; $h_2 - h_3 = 3.5$	128.136
4	$h_2 = h_3$; $h_1 - h_2 = 3.5$	128.5135
5	$h_1 = h_2$; $h_3 - h_2 = 8.71$	129.12
6	$h_1 = h_3$; $h_2 - h_3 = 8.71$	129.828
7	$h_2 = h_3$; $h_1 - h_2 = 8.71$	130.7667

5.4/ Suspension Component Motions

Table 6(a) and (b) shows the actual motion of the suspension walking beams as compared to a theoretical tabulation if the system worked as an ideal suspension.

Table 6/ Comparison Between Walking Beam Displacement (Actual and Theoretical)

(a) Theoretical/Actual w_o, x_o, y_o, z_o = Displacements of Beam at Condition 1.

Condition	$w - w_o$	$x - x_o$	$y - y_o$	$z - z_o$
1	0	0	0	0
2	-1.703/0.476	2.271/-0.635	-3.122/-0.794	+4.162/1.27
3	-2.272/-1.111	3.023/1.117	1.704/2.86	-2.272/-1.905
4	3.973/2.69	-5.297/-2.858	2.27/0.794	-3.027/0.318
5	-4.24/0.635	5.653/-0.9525	-9.893/-3.175	13.191/5.715
6	-5.656/-1.75	7.541/1.905	4.242/5.08	-5.656/-3.81
7	9.886/5.08	-13.181/-5.40	5.65/1.27	-7.53/-0.953

(b) $\left|\left(\frac{\text{Theoretical-Actual}}{\text{Theoretical}}\right)\right| \times 100\%$ Walking Beam Displacements

Condition	w	x	y	z
1	-	-	-	-
2	128	128	75	69
3	51	63	67	16
4	32	46	65	89
5	85	83	68	56
6	69	74	20	33
7	48	59	77	87

Notes:

- 0% denotes suspension behaviour similar to theoretical equalizing axle model.
- 100% denotes suspension behaviour similar to three-axle model.

5.5/ Calculation of Balance Beam Mechanism Spring Stiffness

From Table 6(b), it is apparent that the suspension system behaves similar to a suspension having three individual axles. This being the case, the spring effect originates from the tires, leaf springs, and beam mechanism. The following calculations determine the spring stiffness of the beam mechanism, and hence, its lack of ability to equalize loads.

Figures 13 and 14 show the relative load displacement curves for the tires and springs, respectively. From these, tire spring constants and leaf spring constants were determined.

These were used to isolate the effect that the balancing system had on the overall suspension performance. This can be seen in Table 7. The effect is represented by spring constant $k_{mechanical}$ for axles 5, 6, and 7.

5.6/ Discussion

Figures 15, 16, and 17 compare measured axle loads with the analysis. They reveal that the suspension behaved more like a three-axle group than a triple axle. This finding is supported by the ride height analysis in Figure 18.

Table 6(b) shows that the suspension mechanism modestly attempted to follow design but either fell far short or grossly overshot the balance criteria. This could be as a result of worn and seized rotating members, friction within leaves of the leaf spring, over-tightening of suspension linkage, or binding.

The overall behaviour of the suspension system was very similar to a group of three individual axles, each with an axle spring constant of approximately 788 kg/cm, with preset adjustments (S_1, S_2, S_3) as calculated in Section 5.3. All three axles appeared to behave in a similar manner.

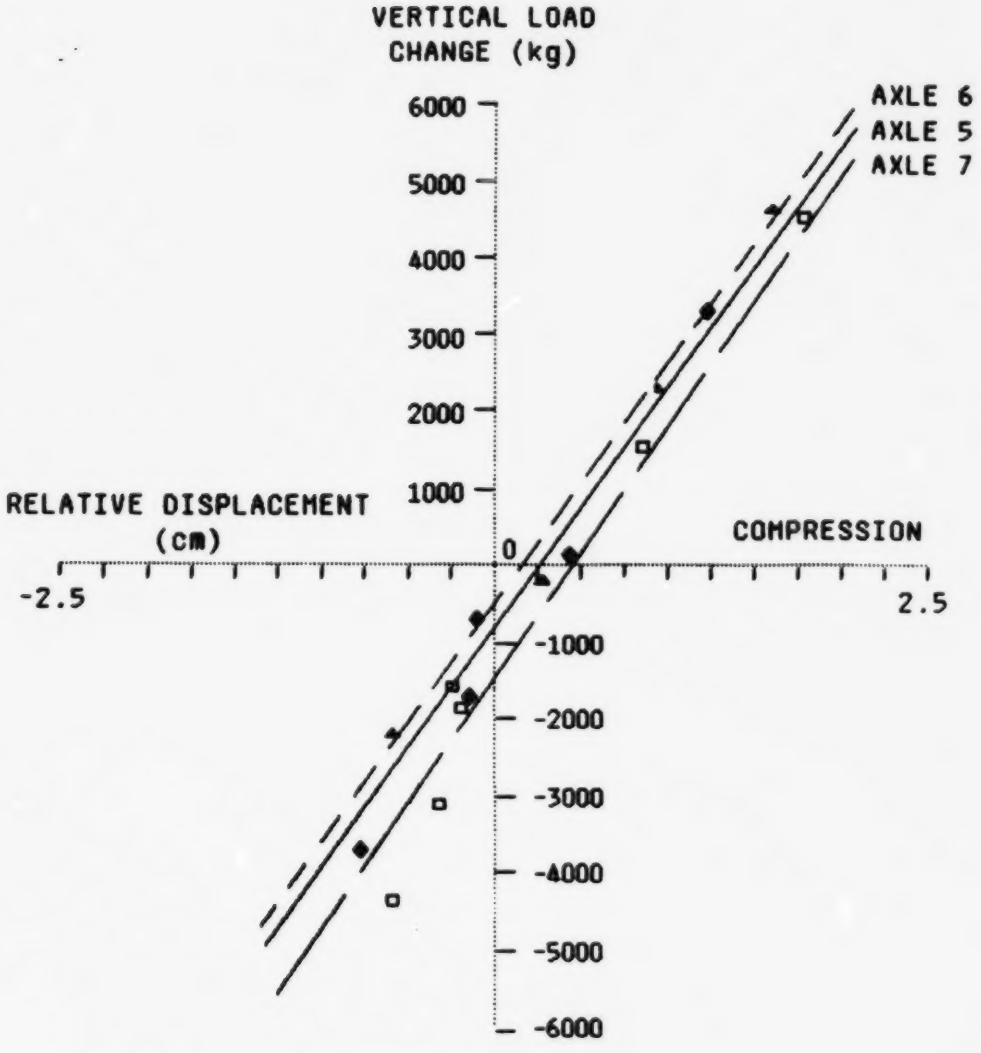


Figure 13/ Relative Load Displacement Curves for Axle 5, 6, & 7's Tires

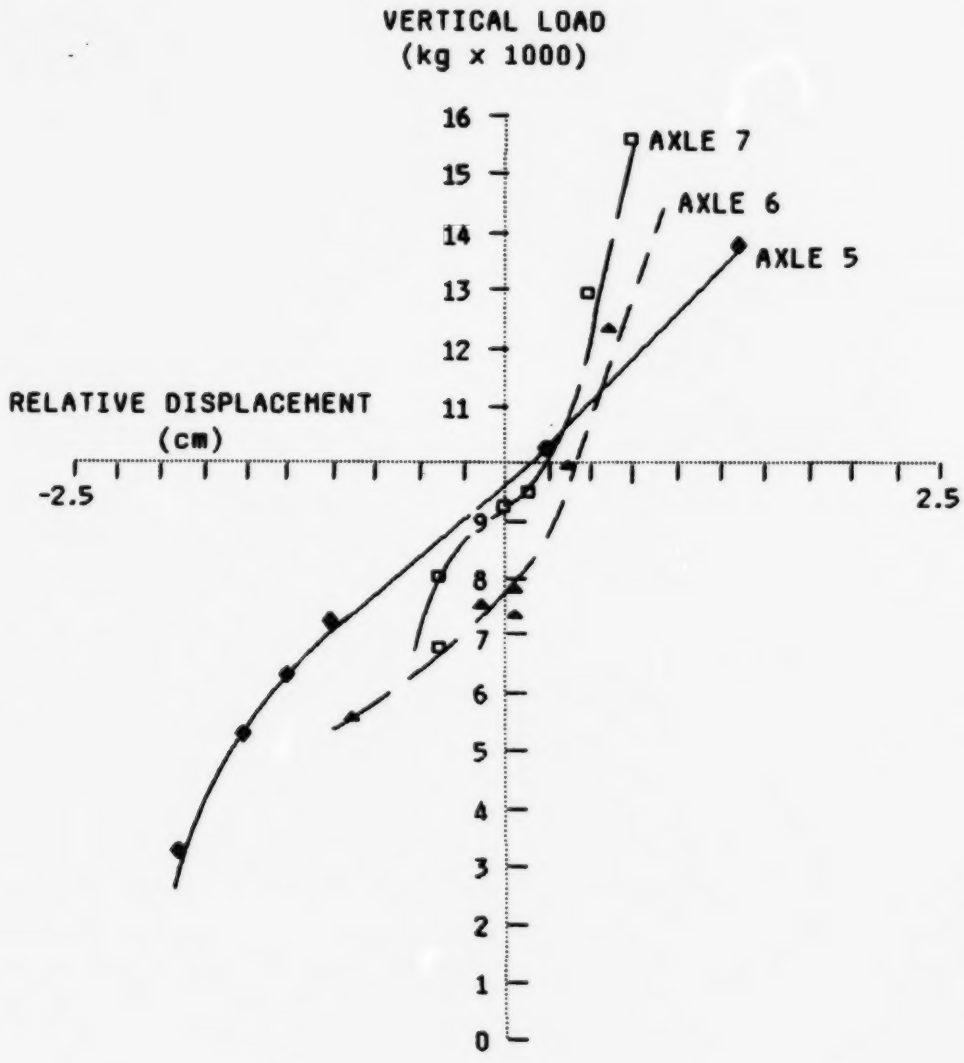


Figure 14/ Relative Load Displacement Curves for Axle 5, 6, & 7's Leaf Springs

Table 7/ Determination of Suspension Mechanism Spring Constant

	Axle 5	Axle 6	Axle 7
K_e = Total System Spring Constant	1431 kg/cm	787 kg/cm	925 kg/cm
K_t = Spring Constant of Tires	3150 kg/cm	3150 kg/cm	3150 kg/cm
K_s = Leaf Spring Constant	2812 kg/cm	7870 kg/cm	7870 kg/cm

$$\frac{1}{K_e} = \frac{1}{K_s} + \frac{1}{K_m} + \frac{1}{K_t}$$

$$\therefore K_{mechanism} = \frac{K_e K_s K_t}{K_s K_t - K_e(K_t + K_s)}$$

K_{tires} K_{spring} $K_{mechanism}$ = $K_{equivalent}$

$$K_{mechanism\ (axle\ 5)} = \frac{1431 \times 3150 \times 2812}{(3150 \times 2812) - 1431(5962)} = 38\ 860 \text{ kg/cm}$$

$$K_{mechanism\ (axle\ 6)} = \frac{787 \times 3150 \times 7870}{(3150 \times 7870) - 787(11\ 020)} = 1210 \text{ kg/cm}$$

$$K_{mechanism\ (axle\ 7)} = \frac{7870 \times 3150 \times 925}{(7870 \times 3150) - 925(11\ 020)} = 1570 \text{ kg/cm}$$

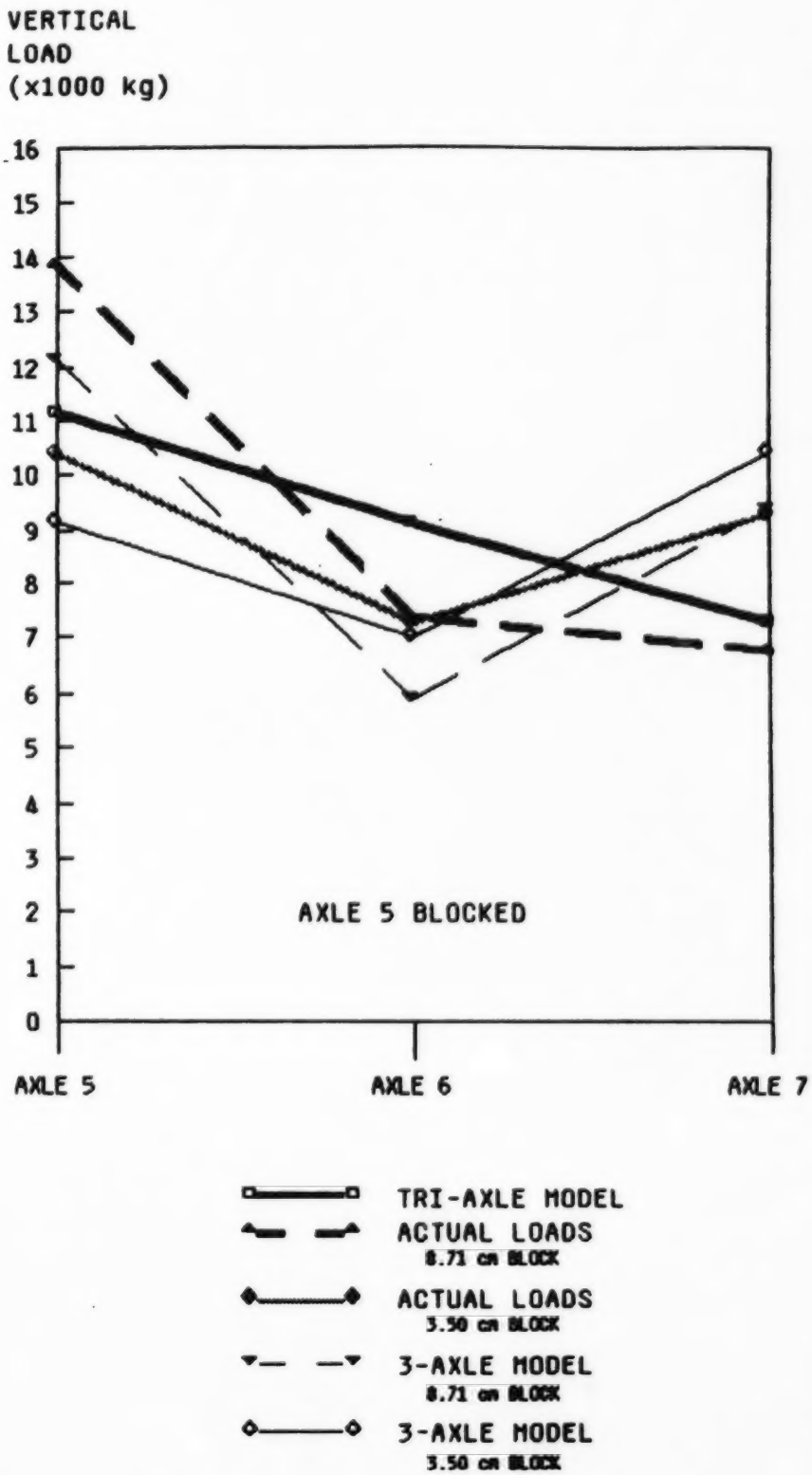


Figure 15/ Loading Comparison Between Models and Actual Axle

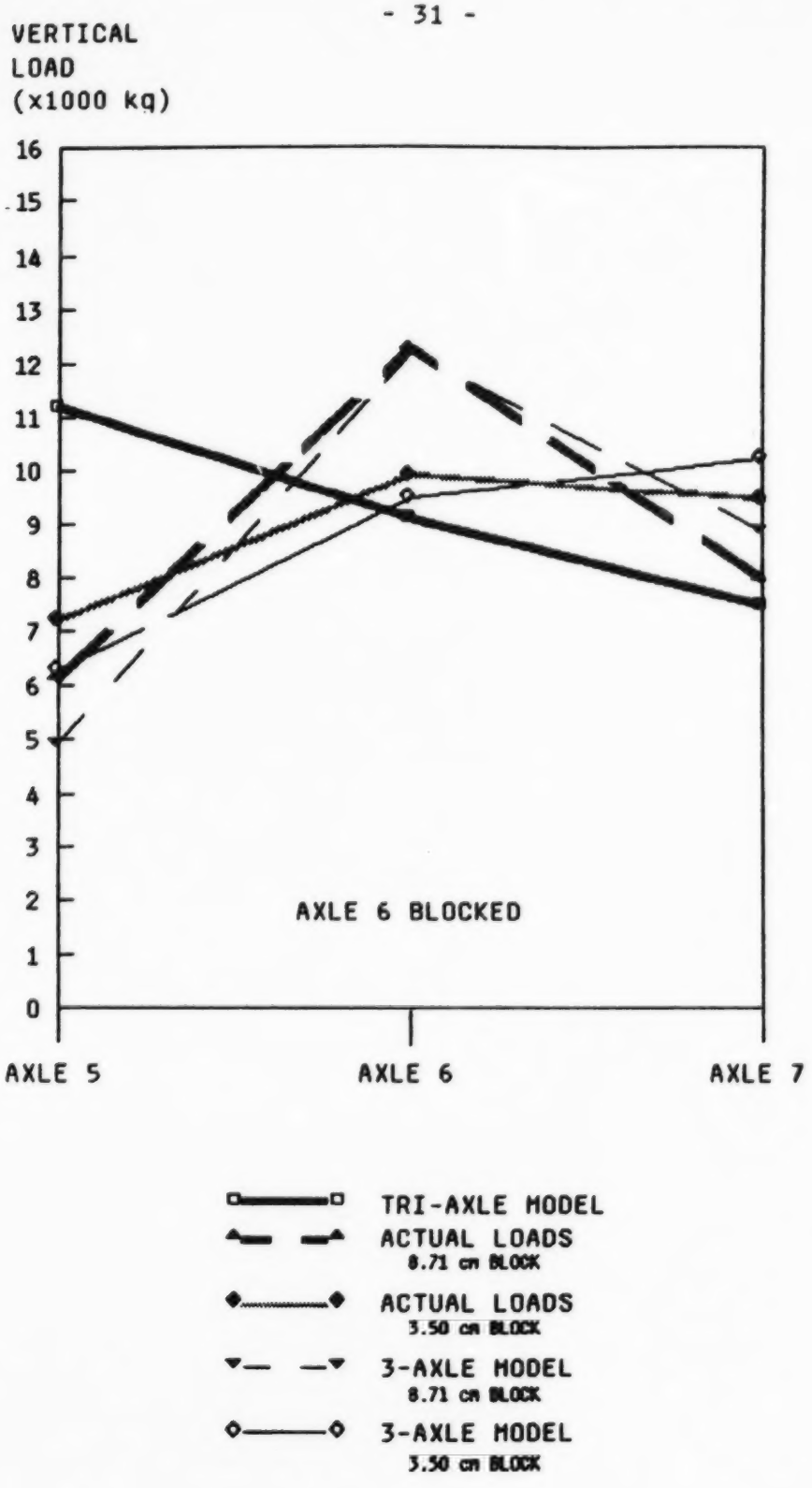


Figure 16/ Loading Comparison Between Models and Actual Axle

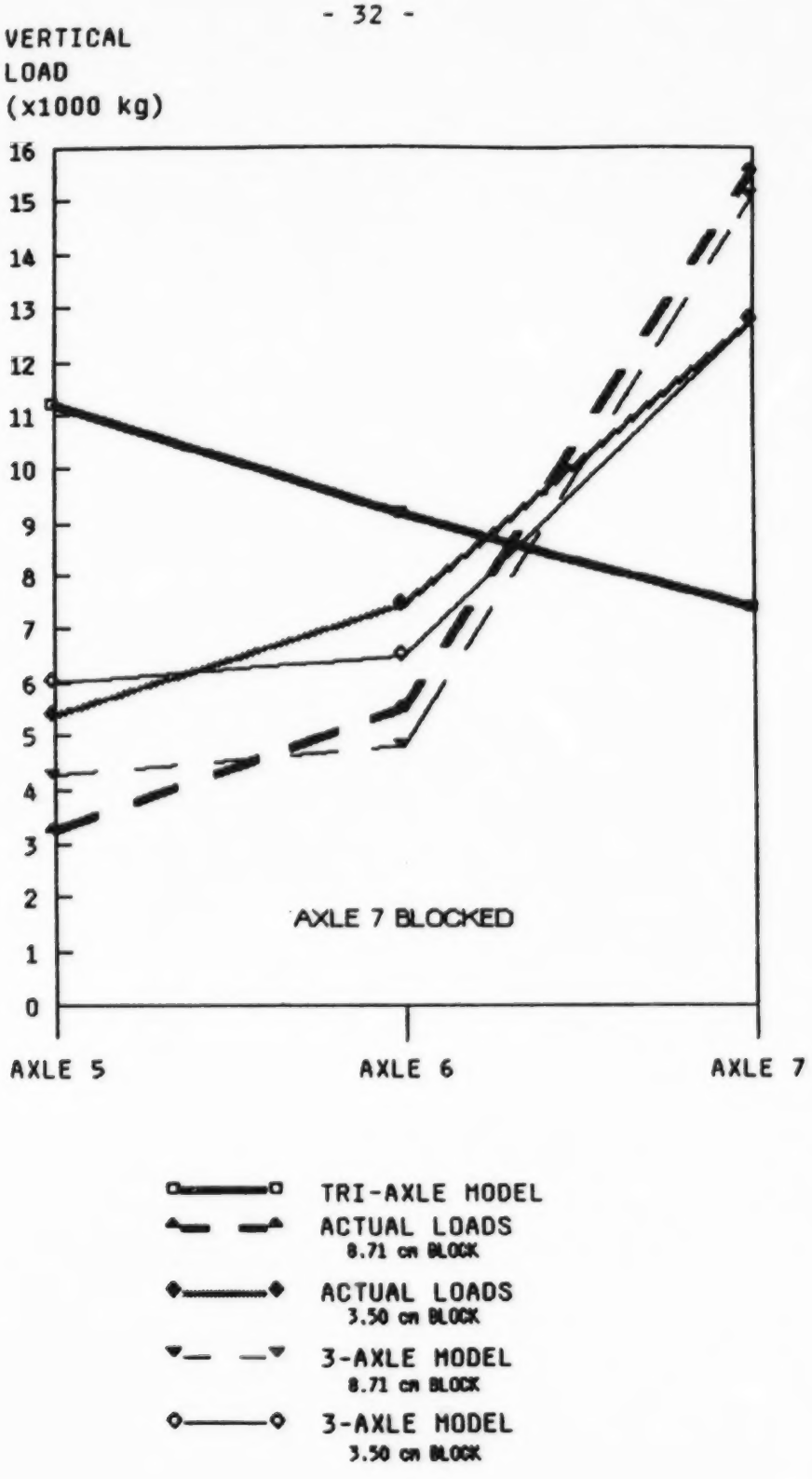


Figure 17/ Loading Comparison Between Models and Actual Axle

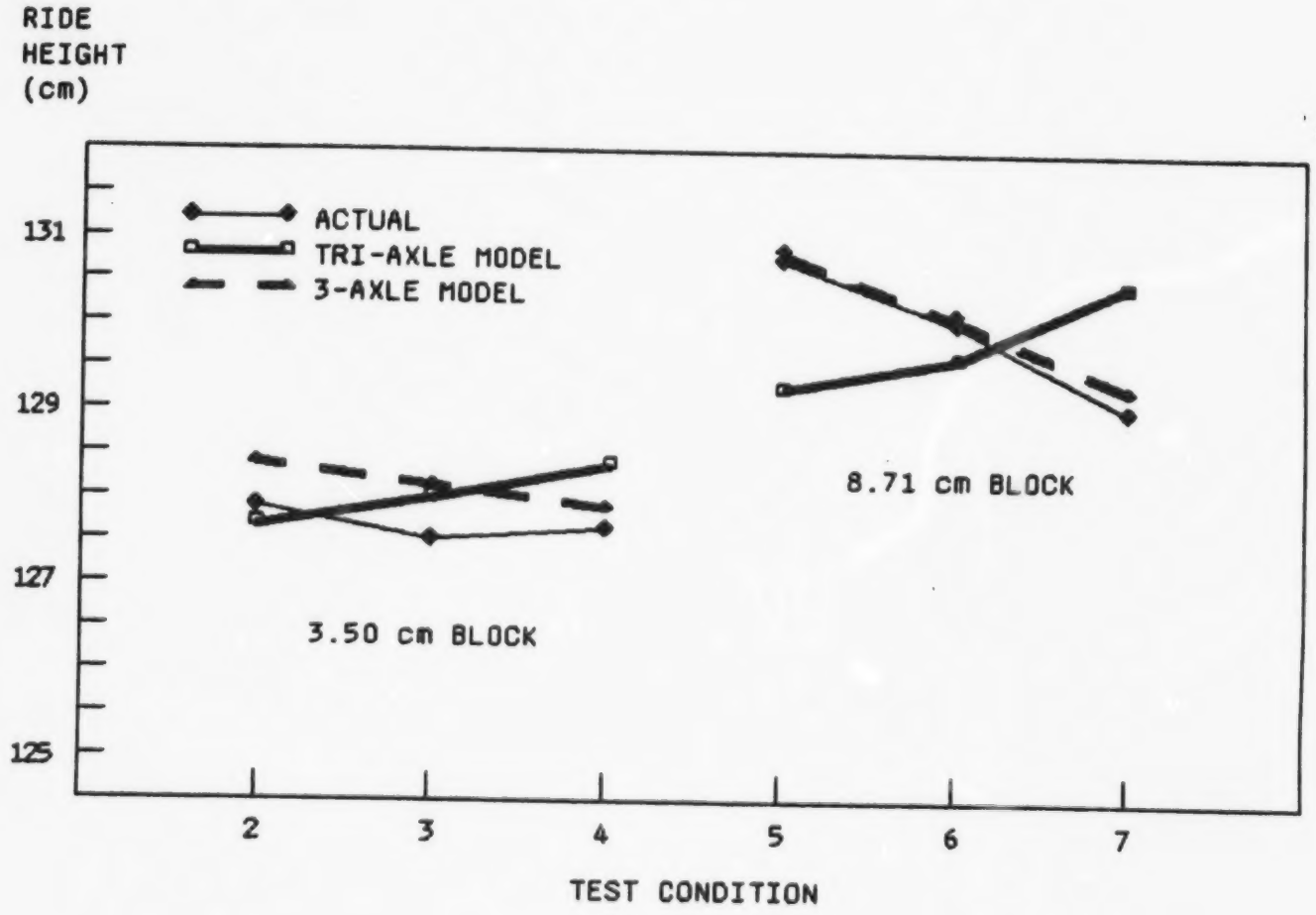


Figure 18/ Ride Height Comparison Between Actual and Model

A close look at Figures 15, 16, and 17 shows a marked similarity in the behavioural trends of the actual truck to that of three individual axles. This observation is totally borne out by the percentage over/under reaction of Table 6(b), which indicates that the system behaviour was markedly toward that of a three-axle system. The mechanism spring constants of Table 7 should have all been zero if this system was to share loads exactly. The constants, however, are all large, indicative of binding or other extraneous seizures. Figure 19 shows this in a graphical context.

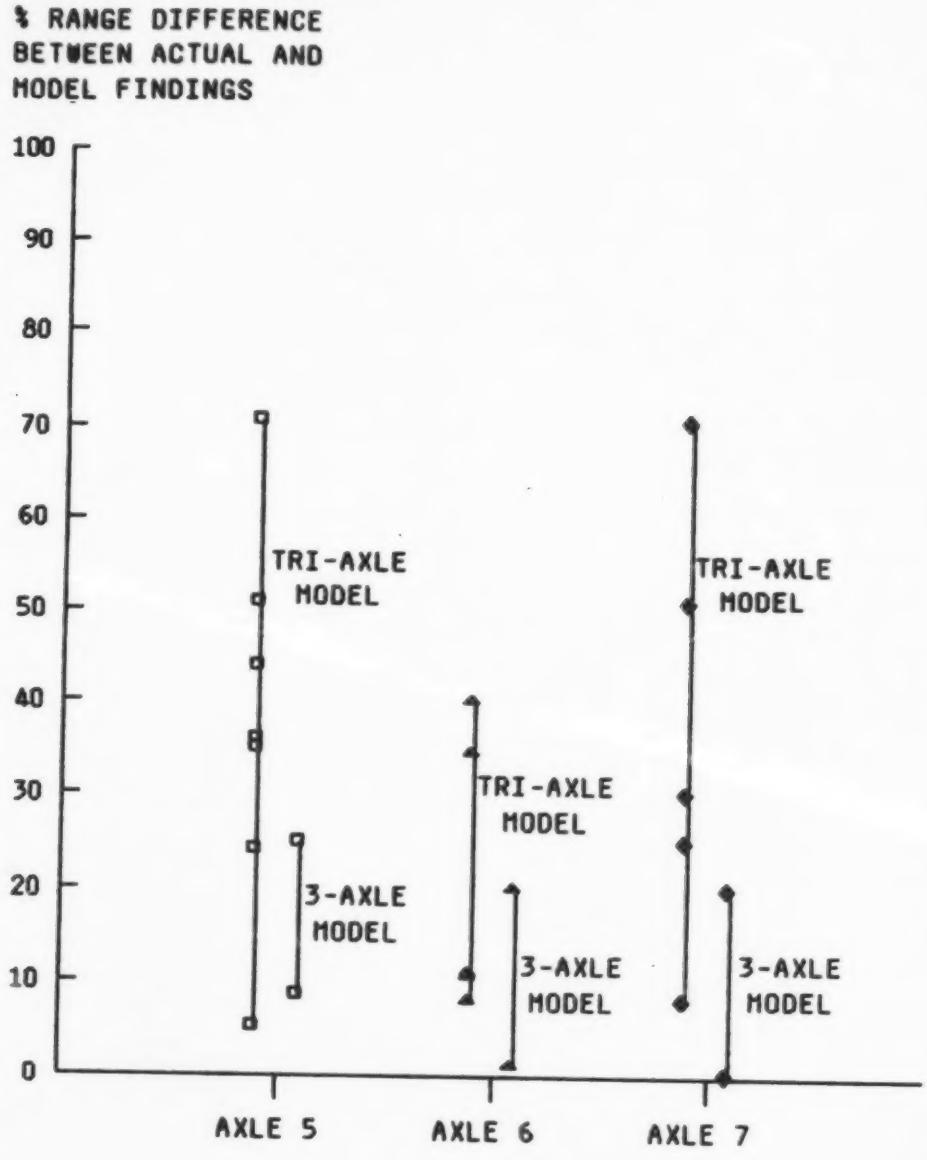


Figure 19/ Percentage Difference Between Actual and Model Results at Three Axles

6/ CONCLUSION

A triple-axle trailer suspension of a type known as the "six-spring" design was tested under various conditions of differential axle load. Analysis of the test results shows that the suspension behaves as if the axles were individually suspended.

While the suspension may be "designed to automatically equalize the load between the three axles under all conditions of loading," it clearly fails to do so. It is also questionable whether the axles are "articulated from an attachment to the vehicle, common to the consecutive axles." Since the suspension tested may fail one of the definitions of a triple axle under the Ontario Highway Traffic Act, and certainly fails the intention, it is concluded that it should more appropriately be considered a three-axle group rather than a triple axle.